# **Introductory Chapter**

# The AMS Ocean Paradigm

Earth is a complex and dynamic system with a surface that is more ocean than land. The ocean is a major component of the Earth system as it interacts physically and chemically with the other components of the hydrosphere, cryosphere, atmosphere, geosphere, and biosphere by exchanging, storing, and transporting matter and energy.

By far the largest reservoir of water on the planet, the ocean anchors the global water cycle—the ceaseless flow of both water and energy within the Earth system. As a major component of all other biogeochemical cycles, the ocean is the final destination of water-borne and air-borne materials.

The ocean's range of physical properties and supply of essential nutrients provide a wide variety of marine habitats for a vast array of living organisms.

The ocean's great thermal capacity and inertia, radiative properties, and surface and deep-water circulations make it a primary player in Earth's climate system. Climate, inherently variable, is currently changing at unprecedented rates largely due to human actions that are altering the environment. This positions climate change as part of a complex, coupled human/natural system in which society impacts and is impacted by the ocean.

Humans rely on the ocean for food, livelihood, commerce, natural resources, security, and dispersal of waste. Humankind's intimate relationship with the sea calls for continued scientific assessment, prediction, and stewardship to achieve and maintain environmental quality and sustainability.

*Ocean Studies* employs an Earth system perspective and is guided and unified by the AMS Ocean Paradigm. The Earth system consists of subsystems (or spheres) that interact in orderly ways, described by natural laws. This text will explore the interactions among these subsystems, the flow and conservation of energy and materials, and how human activity impacts and is impacted by the ocean.

About half of the world's human population lives within a few tens of kilometers of the ocean. A large proportion of the remaining population lives within a few tens of kilometers of a river or estuary that is connected to an ocean. Human settlements and civilization have always concentrated near the ocean or seas; they are important to humans and all life on Earth.

The ocean formed on Earth about 4.6 billion years ago and provided the cradle in which life first evolved about 3.6 billion years ago (Figure IC.1). On the geologic time scale, the entire history of human civilization is like the blink of an eye. Despite this, humans are changing the ocean, just as they are

changing the atmosphere and land, at an unimaginably fast pace compared to the geologic time scales. But are the changes humans are making positive, negative, or neutral? The only way to answer this question is to understand how the ocean, as a major component of the Earth system, has interacted with the other components of the hydrosphere, cryosphere, atmosphere, geosphere, and biosphere over billions of years.



#### Figure IC.1

The history of Earth. The Earth formed about 4.6 billion years ago. Animals have existed on Earth for only an extremely brief period of its history. If the age of Earth were only 1 year, animals would have existed for only 2 months, humans for about 6 hours, and the science of oceanography for less than a single second. Most time periods on the figure are expressed as millions of years ago (MYA). [From Segar, D. A., 2018: Introduction to Ocean Sciences, Fourth Edition. [Available online at <u>http://www.reefimages.com/</u>oceansci.] Used with permission.]

This text explores the fundamental physical, chemical, geological, and biological properties and processes of the ocean and reviews how humans have studied the ocean. To place these concepts into context, it is important to first review the phenomenal range of resources that the ocean provides and how humans have utilized these resources. This text will provide readers with a new appreciation for the intimate and intricate linkages between their lives and the ocean. More importantly, readers will be equipped to analyze, understand, and evaluate the ever-increasing stream of scientific and popular reports from the media to develop sound, logical reasoning concerning the human activities on the ocean.

Scientists investigate important scientific questions facing human society. Specifically, the role of human activity, such as the link between burning of fossil fuels and the release of carbon dioxide and other greenhouse gases to the atmosphere, as it permanently alters the environment. Will these activities alter the ocean and atmosphere to affect global temperature or trigger a mass extinction? This issue is popularly referred to as "climate change," but this question encompasses much more than just changes in climate.

In recent decades, interest in the ocean has grown in response to improved knowledge and understanding of the creatures that inhabit the underwater world, especially coral reefs (Figure IC.2). Scuba diving has become a pastime, avocation, and sport for millions, while even more are fascinated by videos of the amazing array of ocean life. Ocean aquariums in many cities attract millions of visitors every year. A large proportion of recreation or vacation pastimes are directed toward beaches, boating, water sports, and activities. On a more somber note, the death and destruction caused by tsunamis, severe storms, and tragedies, such as shipwrecks and shark attacks, also fascinate and terrify (Figure IC.3). This text offers a comprehensive approach to studying the ocean beyond the issue of climate change. For example, after studying this text, readers will have answers to such questions as:

- Why might someone say that less is known about the ocean than the moon or Mars?
- What is the reason for the location of the world's active volcanoes?
- Why does the East Coast of the United States have barrier islands and tidal wetlands (marshes and mangrove swamps) while the West Coast does not?
- What is a tsunami and what is the best response if a person is on a beach when one is approaching?
- What is a rip current and what are the guidelines for survival?
- What is unique about water and how do its unique properties affect daily life and our environment?
- What do we need to know about the ocean to understand and predict climate changes?
- Why are fisheries concentrated mostly in coastal zones and why do some areas of the coastal ocean produce more fish than others?
- Why do hurricanes impacting the U.S. primarily make landfall along the Gulf of Mexico and East Coast?
- Are oil spills and industrial discharges as damaging as portrayed by news reports?
- What are the main causes of the widely reported destruction of coral reefs and damage to other ocean ecosystems?



**Figure IC.2** Coral reefs are unique and complex systems that support diverse marine life. [Courtesy of NOAA]



Aerial view during an Army search and rescue mission shows damage from Hurricane Sandy to the New Jersey coast, 30 October 2012.

Oceanography is an interdisciplinary science. While some answers may be found in a single section or chapter of this text, most answers require piecing together information from several different chapters. This book provides a roadmap to help the reader navigate the complex interplay between geology, physics, chemistry, and biology.

# IC.1 Why the Ocean is Important to Us

The ocean is fished for seafood and used for transport and recreation while oil and gas are extracted from the ocean floor, making ocean resources valuable to the U.S. and global economy. NOAA reports that the U.S. ocean economy employed 3 million people in 2013. Furthermore, that year the six sectors of the ocean economy accounted for \$359 billion of the U.S. gross domestic product. Those sectors are: marine construction (\$5.8 billion in goods and services), living resources (\$7.2 billion in commercial fishing, aquaculture, seafood processing, and seafood markets), offshore mineral extraction (\$169 billion including oil and gas exploration and production), ship and boat building (\$17.3 billion), tourism (\$97.1 billion), and marine transportation (\$59.1 billion). The following sections provide a brief survey of the range of ocean resources, the benefits to human civilization, and the undesirable environmental effects on the ocean from the ocean economy. For simplicity, this content is grouped into eight categories: biological resources; transportation, trade, and military use; offshore oil and gas; methane hydrates; minerals and freshwater; recreation, aesthetics, and endangered species; energy; and waste disposal.

### IC.1.1 Biological Resources

### **IC.1.1.1 Fisheries**

The fishing industry is estimated to be worth \$285 billion per year worldwide and is a major component of the U.S. economy (Figure IC.4). Seafood has very high protein content, which is of critical dietary importance to communities around the world. In many coastal areas, seafood is the basic subsistence food because no other significant source of food protein is available. Iceland and Pacific Ocean island nations are good examples of such seafood-dependent areas.



#### **Figure IC.4** A commercial fisherman. [Courtesy of NOAA]

Until the past century, fishery resources were essentially inexhaustible because fish reproduced faster than they were removed (Chapter 14). During the past 100 years, human populations swelled and the demand for seafood has increased accordingly. Ocean fishery resources are necessary to feed a hungry and growing population. Consequently, the fishery resources of many parts of the ocean have been exploited so intensively that many species are overfished and can no longer reproduce fast enough to replace their populations (Figure IC.5). Overfishing, which has resulted from a variety of technical and socioeconomic factors, poses perhaps the greatest threat to the health of ocean ecosystems, other than climate change and ocean acidification. The damage to fisheries by unwise management practices has implications for the entire planet.



Previously overfished, the stock of butterfish from the Gulf of Maine to Cape Hatteras was rebuilt in 2014. [Courtesy of NOAA]

The United Nations Food and Agriculture Organization (FAO) monitors fisheries statistics worldwide. FAO estimated that 31.4% of the stocks (usually all of a particular species) in 2013 were fished at a biologically unsustainable level (i.e. overfished). In the United States, the NOAA National Marine Fisheries Service reported that of 233 different fish stocks, 38 (16%) of those stocks were overfished in 2015, down from 23% in 2010. For an overfished stock, a council must form a stock rebuilding plan that reduces fishing, allowing the stock to rebuild to its ideal level.

Fishing also can have adverse effects on marine species that are not the target species or else are dependent on the target for food. Many fishing techniques are not efficient in selecting the target species. Virtually all commercial fisheries harvest bycatch, the "nonvaluable" species that are most often discarded overboard (Figure IC.6). Some of the most damaging fishing practices are now outlawed by most nations, but continue to be used in areas far from surveillance by law enforcement officials. Enforcement of fishing regulations on the high seas is extremely difficult, because no nation can afford to patrol adequately.



Loggerhead turtle escaping a net equipped with a turtle excluder device (TED). [Courtesy of NOAA]

A number of new management concepts are applied to fishery resources to address overfishing. These new approaches include assigning catch quotas to individuals, individual boats, or communities and granting exclusive limited fishing access to defined geographic areas. Each of these regulatory approaches embodies the principle that access to the fishery resources is a privilege that should no longer be open to anyone who chooses to fish. Another conservation approach is to establish fishing-free natural reserves where fish populations can reproduce freely, and is beginning to become more widely applied.

To this day, humans are primarily hunters and gatherers in the ocean, much as Stone Age people were on land. Human development from ocean hunter-gatherer to ocean farmer is long overdue. Mariculture (ocean farming), which has historically only been used on a small scale in very few locations, is developing rapidly (Figure IC.7). Mariculture is prevalent in China, where it has been practiced for thousands of years, and in several other developing nations of the Pacific Ocean basin. The United States ranks 14<sup>th</sup> in mariculture production worldwide, but the NOAA National Marine Fisheries Service estimates that more than 50% of imported seafood is mariculture-produced.



Figure IC.7 Net pen aquaculture in deep coastal waters. [Courtesy of NOAA]

### **IC.1.1.2 Other Biological Resources**

Marine species are an important pool of genetic diversity. Marine species possess unique biochemical methods of defending themselves against predators, parasites, and diseases as well as destroying toxic chemicals. They offer a potential resource for the development of pharmaceutical drugs and pollution control methods. Naturally occurring compounds have been used to design similar molecules with similar properties, which can be industrially produced from widely available materials. Potentially valuable pharmaceutical products have already been isolated from marine species and are being tested for a variety of medical purposes, and a small number have been approved for human use. Like the tropical rain forests of the ocean, coral reefs house the most promising sources of pharmaceuticals because of their extremely high species diversity. They sustain large numbers of candidate species, any one of which may contain numerous chemical compounds potentially valuable as drugs. The search for beneficial drugs and pollution-fighting organisms in the ocean has barely begun.

Marine species also are a resource for the aquarium trade. The ornamental (aquarium) fish market in the United States was estimated be worth about \$3 billion in 2004 (Figure IC.8). Most tropical fishes sold in the aquarium trade in the United States are captured from Philippine reefs, where they are often collected by illegal methods that severely damage the coral reef and other species living there.



Figure IC.8 An amateur aquarium with a variety of fish and plant species.

# IC.1.2 Transportation, Trade, and Military Use

Despite the rapid growth in air transport, surface vessels remain the principal and cheapest means of transporting cargo and people across the ocean. Large numbers of commercial, recreational, and military vessels enter and leave U.S. ports every day, with an estimated \$339 billion in shipped goods handled by U.S. ports in 2012, and the \$37.8 billion passenger cruise industry in 2010 (Figure IC.9). In addition to commercial transportation, the ocean has important military uses. Surface naval vessels ply the ocean, while submarines transport and deploy ballistic missiles. During the past 40 years, intensive efforts have been made to improve ways to hide submarines and find enemy submarines. Extensive oceanographic studies, particularly studies of ocean surface and subsurface currents and of acoustic properties of the ocean, have been conducted to support these efforts.



A container ship. [Courtesy of Robert Schwemmer, NOAA National Marine Sanctuaries]

The benefits from transportation, trade, military, and recreation come at a cost to the ocean environment. Ships, particularly oil tankers, container ships, and naval vessels (especially aircraft carriers and submarines), have become progressively larger. The larger vessels require deeper ports and harbors, which increase the need for dredging navigation channels in many bays, estuaries, and rivers. Dredging damages benthic (bottom living) organisms at the dredging site (Figure IC.10). Dumping of the dredged material, which generally is done at a site in the estuary or coastal ocean not far from the dredging site, also has environmental impacts.





# IC.1.3 Offshore Oil and Gas

Oil and gas are extracted from beneath the ocean floor in many parts of the world, and most of the undiscovered reserves are believed to lie along the coastline beneath the continental shelves and continental slopes. Oil and gas have been produced from wells drilled in shallow water for many years but technological advances have steadily extended capabilities for drilling in deeper and deeper waters, as well as in areas where weather, waves, currents, and sometimes ice conditions are progressively more demanding. Annual production of offshore oil and gas in U.S. waters is valued at \$25 to \$40 billion a year and is a large enterprise throughout the world (Figure IC.11).



### Figure IC.11

Offshore oil platform off the Brazilian coast. [Courtesy of Divulgação Petrobras/Creative Commons]

Oil and gas are used primarily as fuel for vehicles, industry, and heating/cooling, but also are the raw materials for plastics, pharmaceutical and other chemicals, cosmetics, and asphalt. Although fossil fuel burning may be reduced to prevent further buildup of atmospheric carbon dioxide, petrochemicals, and therefore some oil and gas production, will still be needed far into the future.

Occasionally, oil rigs or oil tankers have accidents that spill oil into the ocean. These spills damage marine ecosystem and recreational areas (Figure IC.12). However, oil is a natural substance that is decomposed by naturally occurring microorganisms and research on the environmental impacts of spills show most ecosystems recover completely from oil spill damage within years to a decade or two. Damage is also caused by the dispersant chemicals or other "clean up" methods often used on spills.



A NOAA veterinarian prepares to clean an oiled Kemp's Ridley turtle after the 2010 Deepwater Horizon Oil Spill. [Courtesy of NOAA and Georgia Department of Natural Resources]

### **IC.1.4 Methane Hydrates**

Along the continental margin, organic carbon decomposition produces methane molecules. At a narrow window of temperature and pressure conditions, the methane molecules become trapped within the crystalline lattice of water ice crystals to form a solid combination called "methane hydrate" (Figure IC.13). Brought to Earth's surface, one cubic meter of methane hydrate releases 164 m<sup>3</sup> of methane gas. Methane hydrates were first observed in core samples drilled on land and the ocean floor several decades ago. These hydrates could be a potential source of methane. Although it would still emit huge quantities of heat-trapping carbon dioxide, methane is a cleaner burning fossil fuel. Methane is completely combusted to carbon dioxide and water with virtually no chemical waste byproducts or products of incomplete combustion, such as those produced by the refining and burning of other fossil fuels. Until recently, this resource was not explored because methane hydrates are widely dispersed, usually occurring in the pore spaces of sediments and rocks. They are unstable except at high pressures and low temperatures, so they occur only below a depth of about 500 to 600 m in the ocean. Recent estimates of the extent of methane hydrate deposits suggest that the total world resources may be more than 100 times the total volume of natural gas estimated to be recoverable from world oil and gas deposits. Although most methane hydrates are widely dispersed and probably unrecoverable, removal of 1% of the total would be a huge economic value. Several nations, led by Japan, are currently attempting to recover methane hydrates form ocean deposits.



Close-up of methane hydrate observed at a depth of 1055 m (3461 ft.). [Courtesy of NOAA Okeanos Explorer Program/2013 Northeast U.S. Canyons Expedition]

### IC.1.5 Minerals and Freshwater

Ocean sediments contain vast quantities of mineral and material resources other than just oil and gas (Chapter 11). They include sand and gravel, manganese nodules, hydrothermal minerals, phosphorite nodules, and heavy minerals, such as gold, that are often present in sediments of current or ancient river mouths. Sand and gravel are currently mined in large quantities from the shallow ocean floor and used as construction materials in locations where no local land resources are available. At present, few efforts have been made to exploit other marine mineral resources. Despite the very limited scope of current ocean mining activities, substantial interest exists for future development.

Many mineral resources, particularly manganese nodules and hydrothermal minerals, are found primarily in the deep ocean, far from land (Figure IC.14). The discovery of such mineral deposits has led to extensive oceanographic research to identify the processes that created them and to determine their distribution and abundance. The potential future value of those resources is considerable and several mining operations are under development. The concern is that deep-ocean mining may have significant environmental impacts, especially if large quantities of fine-grained sediment are released into naturally clear waters of the surface, well-lit open ocean (photic zone).



Off the coast of the southeastern U.S., a Pluto skate was found on iron-stained sand bottom with manganese nodules. [Courtesy of Estuary to Abyss 2004/NOAA Office of Ocean Exploration]

The ocean produces both salt and freshwater through evaporation and condensation, respectively. Humans have developed reverse-osmosis extraction units to generate freshwater from ocean water. This process is expensive and energy intensive, but drought conditions and ever increasing population are sure to accelerate it, as is now happening in California. The byproduct is high-salinity, warm wastes discharged to the ocean, which may have adverse effects on the biology of the area.

### IC.1.6 Recreation, Aesthetics, and Endangered Species

Humans enjoy living on the coast, not only for the ocean's food resources, but also for its aesthetic qualities and its moderating effects on climate. The ocean's aesthetic qualities have inspired poets and artists for millennia and today the ocean provides a variety of recreational activities, including sunbathing, swimming, surfing, sailing, luxury cruises, snorkeling, and scuba diving. A much wider spectrum of the human population now considers the ocean environment to be a special part of nature that should not be despoiled. Underwater photography and video and the far-reaching impact of television and the Internet also have introduced many to the beautiful, strange, and alien world of marine life.

### IC.1.7 Energy

As fossil fuels have been depleted, climate change concerns have grown, and nuclear energy has lost favor, a major search has begun for alternate sources of energy. The ocean offers several potential sources of energy, including tides, waves, ocean currents, and thermal gradients, but currently very little energy is generated from any ocean resource. Substantial engineering problems must be solved before ocean energy resources can contribute significantly to global energy demands and questions must be answered about environmental impacts.

The only ocean energy source currently exploited on a commercial scale is the tides. The existing tidal energy technology requires a dam across the mouth of a bay or other inlet where the tidal range is very large. Relatively few locations worldwide are suitable. Because water must be stored behind a dam

during part of the tidal cycle, tidal currents and sedimentation patterns are altered in a way that can be detrimental to benthic biota. The dam also hinders the passage of organisms and vessels.

A number of technologies have been proposed for energy recovery from currents. The most likely technology involves a large number of huge fanlike turbines placed in a current to generate significant power. The nature and scope of possible adverse environmental effects of the proposed technologies are unknown and the major concern is that modifying currents could have other far-reaching effects.

The energy potentially available from ocean waves and currents is truly enormous, but such energy is widely dispersed and not easy to harness. Several design approaches have been developed to extract energy from waves, although none has yet been tested on a large scale. Should a design succeed, it would be placed on the continental margin parallel to the coastline stretching along many kilometers of coast, which could be a navigation hazard and interfere with movements of marine organisms, particularly marine mammals. Even worse, a string of such wave generators along a coast could significantly reduce wave energy at the shore. The result would be to change both the sedimentation regime and the associated biology of the nearshore zone.

The quantity of ocean thermal energy that potentially can be exploited is huge and may be easier to extract than wave or current energy. Ocean thermal energy conversion (OTEC) systems exploit the temperature difference between deep and shallow waters in the ocean to drive a turbine and generate electricity (Figure IC.15). Conventional power plants use heat from burning fossil fuels or a nuclear reaction to vaporize water in a closed container. The resulting high-pressure steam drives a turbine, which is then condensed by cooling water to be recycled. In an OTEC power plant, warm surface waters flowing over heat exchanger tubes heat ammonia. As the ammonia evaporates, the resulting high-pressure gas drives a turbine. Once through the turbine, the ammonia is condensed by cold water pumped up from the deep layers of the ocean. Onshore plants can also be used for desalination. An OTEC power plant is essentially built around a large diameter pipe that reaches to depths from which cold water can be pumped.





Ocean thermal energy conversion (OTEC) uses the thermal differences between shallow and deep ocean water to generate electricity. It can be done most efficiently in the tropics and subtropics. The top figure shows an onshore plant and the bottom an offshore plant. [Figure redrawn from NOAA images]

OTEC is very promising and is probably the form of ocean energy generation likely to contribute most significantly to world energy needs. However, OTEC can be used efficiently only where surface waters are warm and cold deep waters are accessible year round, limiting it to tropical and subtropical latitudes. In North America, only a few coastal locations, such as Hawaii, where an operating prototype and research OTEC facility has been operational since the 1980s, and the east coast of South Florida, are suitable. Pacific island nations are perfect locations, but the considerable investment needed to develop and build OTEC power plants is difficult for such nations to afford. Several nations, including Japan, are currently planning or developing OTEC power plants.

### IC.1.8 Waste Disposal

The ocean has been used for waste disposal for thousands of years and, for most of that time, without significant harm to the marine environment. In fact, use of the ocean for sewage waste disposal has historically proven to be one of the most effective advancements ever made in human health protection.

Oceanographic research has documented a variety of problems caused by the disposal of certain wastes in parts of the ocean (Chapter 14). Ocean waste disposal is now severely restricted and strictly regulated by International Law. However, the ocean continues to be used for disposal of some wastes, and this may be the most environmentally sound management approach available.

Most of the wastes currently disposed in the ocean are liquids or slurries discharged through pipelines, called outfalls, into rivers, estuaries, or the coastal ocean. Materials disposed of in this way include treated sewage effluents and treated industrial waste or cooling water. At one time, quantities of a variety of solid wastes, including chemicals, low-level radioactive wastes, construction debris, and trash, were transported to sea on vessels and dumped. Almost all dumping of solid wastes in the ocean has now ended. Dredged material is the only waste material dumped at sea from vessels in large quantities.

# IC.2 The Ocean and the Origins of Life

The most valuable "resource" provided by the ocean does not fall into one of the categories discussed in the previous section. That resource is the oxygen that all animals breathe. To understand this, it is important to look back at Earth's early history. While many questions remain surrounding the origins of life on Earth, scientists point to life as beginning billions of years ago. The ocean has played a key part in its development (Chapter 1).

All life depends on the transport of chemical elements and compounds within cells and between cells and the surrounding environment. In all known living organisms, from archaea (microbial organisms unknown until recent decade but likely the most abundant group of species on Earth) to mammals, chemical substances are transported dissolved in water. Therefore, water is essential to life. It is not surprising that life appears to have been nurtured and developed in the ocean. Evidence from the fossil record indicates that the first known life forms were bacteria-like microorganisms that existed about 3.6 billion years ago (Figure IC.1), approximately 1 billion years after Earth formed.

When the ocean first formed about 4 billion years ago, the atmosphere consisted mostly of nitrogen, with smaller amounts of carbon dioxide and methane. Free oxygen in the atmosphere and ocean did not exist. It is thought that some of the earliest life forms were similar to the chemosynthetic microbes that are found at present in many isolated environments, such as hydrothermal vents (Figure IC.16) and deep within Earth's crust. These environments contain little or no free oxygen and are often characterized by conditions of extreme temperature and pressure, similar to the conditions that may have existed in the early ocean. These early life forms used chemical energy to produce food. At some unknown time, microorganisms began to use the Sun's light energy during photosynthesis to produce food. Early pho-

tosynthetic species probably used hydrogen sulfide as their source of hydrogen, which is needed for building chemical compounds. Later, photosynthetic microorganisms developed the ability to split water molecules, using the hydrogen to build their chemical compounds and releasing oxygen in the process. Over 1 and 2 billion years, these photosynthetic organisms changed the composition of Earth's ocean and atmosphere. The concentration of oxygen steadily increased until reaching modern levels. As the free oxygen increased in the ocean, it reacted with sulfides and other chemical compounds that supported the life cycles of chemosynthetic species. As a result, chemosynthetic species largely disappeared or remained restricted to extreme environments. Furthermore, the free oxygen permitted the development of more complex organisms.



### Figure IC.16

Sully Vent covered with tube worms in the Main Endeavour Vent Field in the northeast Pacific ocean basin. An acoustic hydrophone and resistivity-temperature-hydrogen probe surround the vent. [Courtesy of NOAA Pacific Marine Environmental Laboratory (PMEL) Earth-Ocean Interactions (EOI) Program]

The ocean and atmosphere reached a steady state (maintaining approximately the same chemical compositions that they have today) about 1 billion years ago. The first primitive higher animals were marine invertebrates, perhaps similar to sponges and jellyfish, that developed about 700 million years ago. The first fishes developed about 500 million years ago (Figure IC.1). The first plants appeared on land about 430 million years ago and the first mammals only about 220 million years ago. Humans are recent additions to the animal kingdom. Hominids (humanlike species) have existed for only about 4 million years, less than one-tenth of 1% of the history of Earth.

Free oxygen in the atmosphere and ocean is essential to life. This oxygen was supplied initially by 1 billion years of photosynthesis and maintained by photosynthetic microbes in the ocean. Human existence depends on the continued success of the ocean microbial community. Industrial civilizations are barely 200 years old, the ocean have existed for about 20 million times longer, yet within those 200 years, humans profoundly changed both the atmosphere and ocean as discussed in the following section and throughout this text.

# **IC.3 The Ocean and Earth's Environment**

Only very recently have scientists observed the profound changes produced by humans, not just in local environments but in the global ocean, atmosphere, and terrestrial environments as a whole. Too little is known about the global or regional consequences of environmental changes already caused by human activities. Even less is known about the future environmental consequences if civilization maintains its current pattern of exponential development and growth. The urgent need to assess the unknowns has been felt throughout the environmental science community. The oceanographic community has been particularly affected because most global environmental problems involve the ocean and ocean ecosystems. The cumulative knowledge of the ocean is much poorer than knowledge of the terrestrial realm.

Humans have caused significant modifications to the marine environment, including numerous forms of pollution and physical changes in the coastal environment. Information must be obtained by different oceanographic disciplines before human impacts on the ocean can be identified, assessed, and effectively managed. In this text, references are available that explain the application of various oceanographic findings, principles, or studies of ocean management. These resources can help facilitate understanding of problems reported in the media.

Among contemporary environmental issues associated with human activities, two stand out as the most important and complex: global climate change primarily caused by excess carbon dioxide in the atmosphere (Chapter 12) and acidification of the ocean (Chapters 3 and 12). Earth's atmosphere keeps Earth's average surface temperature considerably warmer than it would be without an atmosphere. In the atmosphere, several gases, especially carbon dioxide, absorb and emit longwave radiation. Since the Industrial Revolution, the burning of fossil fuels has steadily increased the concentration of carbon dioxide in the atmosphere (Figure IC.17). The concentrations of other greenhouse gases, such as methane, nitrous oxide, and chlorofluorocarbons, also are increasing as a result of human activities. Even if the concentration of greenhouse gases in the atmosphere became steady, Earth's temperature will still rise for many decades to come. Many scientists believe that anthropogenic (originating in human activity) sources have already caused the average temperature of Earth's lower atmosphere to rise perhaps 1 to 2 °C (Figure IC.18). Scientists also predict that the temperature will rise by several degrees Celsius in the next two to three decades.



Change in the concentration of carbon dioxide in the atmosphere since 1880. Data for the smooth part of the curve were obtained from ice cores. Data from 1960 were obtained from direct measurements at Mauna Loa, Hawaii, and show both annual oscillations and a long-term upward trend. The upward trend continues. The monthly average passed 400 for the first time in early 2014. [From Segar, D. A., 2018: Introduction to Ocean Sciences, Fourth Edition. [Available online at <a href="http://www.reefimages.com/oceans-ci.">http://www.reefimages.com/oceans-ci.</a>] Used with permission. Updated data from NOAA Earth System Research Laboratory (ESRL) Global Monitoring Division]



Diagram showing the close relationship between variations in average air temperature and atmospheric carbon dioxide concentrations during the past 160,000 years. These data were obtained from an ice core drilled into the Antarctic ice cap. Notice that Earth's average temperature at present is approximately at its highest level since more than 120,000 years ago. [From Segar, D. A., 2018: Introduction to Ocean Sciences, Fourth Edition. [Available online at <u>http://www.reefimages.com/oceansci</u>.] Used with permission. Adapted from R.C. Scott, *Introduction to Physical Geography*, West Publishing, St. Paul/Minneapolis, 1996]

Both global warming and ocean acidification are attributed to the release of large quantities of carbon dioxide to the atmosphere, primarily as a result of fossil fuel burning. However, the effects of ocean acidification are harder to observe.

Much of the carbon dioxide released by burning fossil fuel has been absorbed by the ocean and the added carbon dioxide reacts to form a weak acid, carbonic acid. Consequently, although ocean waters are still weakly alkaline, the acidity of the ocean is rising. The ocean has been more acid in the ancient past than today, but the rate at which acidification is taking place is thought to be much faster than has ever occurred before. Species cannot evolve and adapt fast enough, which may lead to the extinction of many marine species and drastically altered marine ecosystems. Species that are especially at risk include those within coral reefs and any that create hard parts (skeletons, shells, and other structural materials) of a form of calcium carbonate called aragonite. These species include many of the most important groups of marine organisms, such as shellfish and pteropods, which are the base of marine food chains. Current understanding of the acidification process suggests that to protect ocean ecosystems, humans must not only reduce the amount of carbon dioxide released to the atmosphere within the next few decades, but they must also remove excess carbon dioxide from the atmosphere.

An increase in the global temperature will cause sea level to rise both as the result of thermal expansion of the warmed ocean water and from melting of ice sheets in Greenland and Antarctica. Some experts predict that sea level will rise a meter or perhaps more during the next several decades. If this happens, large areas of low-lying coastal land will be inundated and entire low-lying island chains may disappear.

The ocean and atmosphere act together as parts of a complex system that regulates our climate and the concentrations of carbon dioxide and other gases in the ocean and atmosphere. The ocean captures, stores, and redistributes the Sun's heat energy to the atmosphere. The ocean is integral to weather and climate. Within the ocean-atmosphere system, numerous complicated changes and feedbacks occur as a result of increases in atmospheric concentrations of carbon dioxide and other greenhouse gases. Some changes would add to the predicted global warming, whereas others would reduce or even negate it. However, current understanding of the ocean-atmosphere system is incomplete, especially those segments of the system that are associated with ocean processes. Understanding the ocean is key to improving future climate predictions.

In addition to studying contemporary ocean processes, oceanographers study the ocean to uncover important information about past global climate conditions. Ocean sediments provide a wealth of information about how Earth's climate has changed over tens of millions of years. Scientists and policy makers use this information to assess how climate conditions might change in the future, either as a result of natural changes or as a result of the enhanced greenhouse effect.

# IC.4 Humans and the Ocean

It is clear that humans have interacted with the ocean in positive and negative ways (Chapter 12). Humans have altered the Earth system to such an extent that human activity is equal in magnitude to many geological processes. Humans have impacted the orderly functioning of the ocean (and other components of the Earth system) by altering or disrupting the equilibrium of biogeochemical cycles. Agriculture, mining, and electrical power generation are examples of human activities that affect the ocean and other components of the Earth system. Most of the waste byproducts of these activities are widely distributed by winds and/or rivers that discharge into the ocean. Future scientists will see these products of human civilization as a sharp change in the geological record. To account for the dramatic impact humans have on the planet, many scientists propose naming a new geological era, called the Anthropocene. The last era, the Cenozoic, began with the extinction of the dinosaurs. Human activities have led to a dramatic increase in the rate of species extinction, both on land and in the ocean. In fact, many scientists think that this rise in extinction rate may signify the beginning of a new mass extinction of species on the planet, again perhaps as large as the era that heralded the end of the dinosaurs.

The ocean affects humans for many reasons, especially through its influence on weather and climate (Chapter 4). Ocean waters have a relatively great thermal inertia (degree of slowness in temperature change) so that localities immediately downwind from the ocean have a maritime climate with less summer-to-winter air temperature contrast than inland localities. Among other things, this affects the energy demand for space heating and cooling. The global-scale ocean and atmosphere circulation transports heat energy poleward, which maintains the air temperature gradient between the equator and poles. As a key player in Earth's climate system, the ocean has a generally stabilizing effect on short-term climate fluctuations and is an important factor in multi-year climate variability (e.g., El Niño). The ocean also provides a sink for carbon dioxide and excess solar heat so it helps to slow long-term (e.g., global warming) climate change, but not to stop it.

The consequences of global warming include melting glaciers and ice sheets, thermal expansion of ocean water, and rising sea level. Shrinking sea ice cover in the Arctic is likely to exert a positive feed-

back (which amplifies or intensifies an original process) that will accelerate warming and melting of sea ice and permafrost in the Arctic region. The impact of global warming on marine organisms and ecosystems is likely to be far-reaching and disruptive. The ocean can be responsible for coastal flooding and extensive beach erosion, both of which are expected to increase as climate warms. The ocean supplies latent heat for hurricane (and other tropical storm) development and global warming may lead to stronger hurricanes.

Humans depend on the ocean for water, food, and other resources. Through the global water cycle, water eventually falls to Earth's surface as precipitation that replenishes freshwater supplies. Climate change will alter the location and amounts of rainfall and threaten fresh water supplies in some areas. Marine ecosystems are an important source of food, but some human activities threaten that food supply. Overfishing, bycatch, and introduction of exotic species are among the most challenging problems.

In addition to climate change and ocean acidification, runoff offers another major human impact that may cause damage to ocean ecosystems and the food they supply. The effect of runoff of excess nutrients (i.e., nitrogen and phosphorus compounds) from land to sea affects food supplies from the ocean (Chapter 8).

With continued rapid population growth in the coastal zone, humans become more vulnerable to natural hazards imposed by the ocean, including storm surges (generated by tropical cyclones or other coastal storms) (Figure IC.19), tsunamis (most triggered by submarine earthquakes), and seiches (caused by atmospheric conditions or earthquakes) (Chapter 7). Humans alter the coast for many reasons including to control flooding from storm surges and sea level rise; preserve recreational beaches; maintain harbors and navigation channels; and protect homes, roads, and other structures from wave erosion or slumping of coastal bluffs. In some cases, human activity actually exacerbates these hazards by developing barrier islands, removing protective mangrove swamps, or armoring the coastlines. These strategies often are ineffective in the long-term, prompting other approaches that seek to accommodate rather than confront the forces of nature (e.g., strategic retreat). Everything built on the coast will come under increasing attack as climate warms and sea level rises.



Storm waves and surge cut across the barrier island at Mantoloking, NJ, eroding a wide beach, destroying houses and roads, and depositing sand onto the island and into the back-bay. The yellow arrow in each image points to the same feature. [Courtesy of USGS]

# **Conclusions**

This introductory chapter has touched on many aspects on how human activities affect the ocean and are affected by the ocean. It plays a major part in the lives of everyone and deserves careful attention. This textbook provides an overview of the complexity of ocean and atmospheric environmental issues. Current and future generations must make important decisions about human use and protection of Earth's environment, including the ocean, and everyone should participate in these decisions with an understanding of the uncertainties inherent in all scientific studies and predictions of complex environmental systems. It is essential to recognize that science cannot provide definitive answers to even the most intensively studied environmental problems but, with more information, human society can make better decisions.

# Web Resources

NOAA National Ocean Service - http://oceanservice.noaa.gov/

NOAA National Marine Fisheries Service - http://www.nmfs.noaa.gov/

# **Scientific Literature**

- FAO, 2016: FAO yearbook: Fishery and Aquaculture Statistics. 76 pp. [Available online at http://www.fao.org/3/a-i5716t.pdf]
- FAO, 2016: The State of World Fisheries and Aquaculture 2016. Contributing to food security and nutrition for all. 200 pp. [Available online at <u>http://www.fao.org/3/a-i5555e.pdf]</u>
- Lowther, A., and M. Liddel, Eds., 2015: Fisheries of the United States, 2014. U.S. Department of Commerce, 129 pp. [Available online at <a href="https://www.st.nmfs.noaa.gov/Assets/commercial/fus/fus14/documents/FUS2014.pdf">https://www.st.nmfs.noaa.gov/Assets/commercial/fus/fus14/documents/FUS2014.pdf</a>]
- National Oceanic and Atmospheric Administration (NOAA), Office for Coastal Management. 2016: NOAA Report on the U.S. Ocean and Great Lakes Economy, 23 pp. [Available online at <u>https://coast.noaa.gov/data/digitalcoast/pdf/econ-re-port.pdf]</u>
- U.S. Department of Transportation, 2016: Freight Fact and Figures 2015. 99 pp. [Available online at <u>http://www.rita.dot.gov/</u> <u>bts/sites/rita.dot.gov.bts/files/FFF\_complete.pdf</u>]